Extended Laser Line Scan Optical Imaging System Characterization

Jules S. Jaffe
Scripps Institution of Oceanography
University of California, San Diego
La Jolla, CA 92093-0238
phone: (858) 534-6101 fax: (858) 534-7641 email: jules@mpl.ucsd.edu

Award Number: N00014-07-1-0317
http://jaffeweb.ucsd.edu/

LONG-TERM GOALS

Our overall goal is to develop a "next generation" underwater optical imaging system. The system is predicted to have extended range performance (> 3 total attenuation lengths).

OBJECTIVES

Under an ONR funded SBIR program Phase II with Aculight Co. (Bothell WA), we have received and are testing a new laser line scan system. This proposal requested additional funds to support and extend those tests by allowing enhanced characterization of the environment as well as data collection with higher dynamic range and speed. Enhanced processing of the data will also be accomplished with additional computer facilities.

APPROACH

One of the most difficult imaging situations is when looking through turbid media. Motivated by the many applications that occur in medical, environmental, and the military, there has been a prevailing need for either formulating better imaging geometries or understanding the limitations of the existing ones.

The achievable resolution in turbid media is typically limited by the severe scattering that photons are subject to when transiting back after reflection from a target of interest. This is in contrast with many areas such as optical microscopy and semiconductor wafer inspection, where more often than not, resolution is imposed by the diffraction limit.

The most conventional and oldest method of forming images is when a subject is illuminated by a light source with a broad beam pattern. The light reflected from the target can then be "imaged" by some type of camera system. Under the assumption that the observed resolution is limited by the point spread function (psf) of the medium, a simplifying assumption represents the observed image, $I(x',y')$ as a convolution of the medium psf with the reflectance map, $\rho(x,y)$ so that $I(x',y') = psf(x,y) \otimes \rho(x,y)$ ($\otimes$ is the convolution operator). Equivalently, the observed image can be represented as $I(x',y') = \int I(x,y)\, psf(x'-x, y'-y)dxdy$. The linear systems theory that describes this process has been extensively covered in standard texts.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2008**	2. REPORT TYPE	3. DATES COVERED **00-00-2008 to 00-00-2008**
4. TITLE AND SUBTITLE **Extended Laser Line Scan Optical Imaging System Characterization**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California San Diego,Scripps Institution of Oceanography,La Jolla,CA,92093**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

One common goal in imaging research has been to increase spatial resolution. This has been pursued in both hardware through the design of sophisticated systems, and also in software through the use of signal processing algorithms. As one option, common in microscopy, the use of a scanning source and receiver can present substantial advantages over non-scanning systems. So, for example, in the case of confocal optical imaging, the observable diffraction-limited point spread function is the square of the more traditional, non-confocal point spread function. This leads to increased image resolution via a narrowing of the overall system point spread function.

Under almost all circumstances, underwater viewing is limited due to the turbidity of the environment. The effect of the suspended water, particles, and organisms is to both attenuate and scatter light. The ranges at which informative images can be obtained vary greatly. In practice, under the most ideal situations, ranges of less than a hundred meters are possible. A complicating factor is the severe backscatter, or volume scatter, which creates a large veiling glow that shrouds image contrast. Practical solutions in order to circumvent this effect concern the use of either large camera light separation, scanned, or pulsed systems.

The latest generation of underwater optical imaging systems are not limited by this backscatter effect and are constrained more by the spatial low pass nature of the forward scatter of light as it travels to the camera after reflection from the target. One class of underwater imaging systems that has shown good performance is known as the Laser Line Scan Systems. These systems have been developed over the last decade and have been used primarily to image the sea floor and objects on it.

The Aculight-SIO Laser Line Scan System:

Under current ONR funding, a prototype of a new type of underwater laser line scan system has been delivered to SIO. This system incorporates a 1 MHz repetition rate of 3.5 nsec pulse length laser. The laser is packaged inside a housing that incorporates multiple PMT's and a reflective dome. Figure 1 is a photograph of both the control unit (a), and the dome and scanning unit (b). The detailed characteristics of the LLSS are listed in Table 1.

Figure Unavailable

(a)

(b)

Figure 1: The Aculight - SIO prototype Laser Line Scan System. (a) The LLSS control panel. (b) The laser head, including the packaged laser and the reflective dome, contained in the cylinder at the right side of the photograph.

Table 1: Aculight - SIO Laser Line Scan System Specifications

Laser Performance Specifications:

Pulse Repetition Frequency: 1 MHz
Pulse width: 3.5 nsec
Duty Factor: 0.35%
Emission Wavelength: 532 nm
Max Optical Pulse Energy <6 μJ (@ 3.5 ns)
Max Peak Power: 1.8kW
Average Power High Power Mode: 6W @ 532nm
Low Power Mode 0.3W @ 532nm
Triggers Internal Trigger

Physical Dimensions:

Dimensions (control box: laser scan system): 19 x 18 x 5 1/4 : 10 x 28 x 10.75
Weight: 30 lb: 33 lb
Cooling: Air Cooled: Air Cooled

As can be seen from the table, the device represents a state-of-the-art and entirely new use of laser fiber technology in order to create a high-powered laser line scan system that can ultimately be deployed on an Autonomous Underwater Vehicle (AUV). This is because system power consumption is low and portability (via repackaging of the control electronics) is now possible. The goal of the work requested here is to perform a system characterization via both experimental and theoretical analysis.

This program enhancement is designed to support the acquisition of several hardware devices in order to further and enhance the goals of the above program. Here, we proposed to acquire several devices: 1) A suite of Wet Lab underwater optical attenuation and scattering meters, 2) A Dell PowerEdge Rack 900 Computer System, and 3) A Tektronix DPO4101 1 GHz 4 channel Color Scope. The Wet Labs instruments will allow us to characterize the environment in the Deep Tank so that we can make the correspondence between system performance and range as described as above. Both absorption and scattering measurements will be performed. Note that the instrument package includes a backscatter meter so that an estimate of the water backscatter at the wavelength of the laser (532 nm) will be performed. The Dell computer will facilitate Dr. Jaffe's work on image simulation. These numerical calculations are quite computer intensive. This new Dell system will permit faster "run times" for the computer code thereby enhancing our productivity via more immediate inspection of the results. Additional accuracy will also be achieved with this increase in computing power. The Tektronix scope will allow us to upgrade from our much older instrument. This scope has fast data acquisition capability and, therefore, can be used to directly visualize the output of the Photomultiplier Tube circuit. This will be valuable for setting up the system as well as data collection. As part of this program, we are performing system simulations in addition to the experiments described below.

RESULTS

Upon receipt of the Aculight laser line scan system in April 2008, we initiated a program to characterize the system response to test targets when seen through turbid media. These experiments

have been progressing as we continue to refine both the experimental protocol and the analysis of the results. Here we present the results of several tests where a test target was scanned with the 3 active PMT channels from the SIO-Aculight Laser Line Scan System. These initial results are promising, however, the continuation of this program over the next several months will allow us to quantify and characterize the system in more detail. Future operations will be to move the experiments to the SIO deep tank where we will characterize the system's response at ranges of 10 meters to varying water types. Figure 2 (below) shows the nature of lab experiment that is reported here.

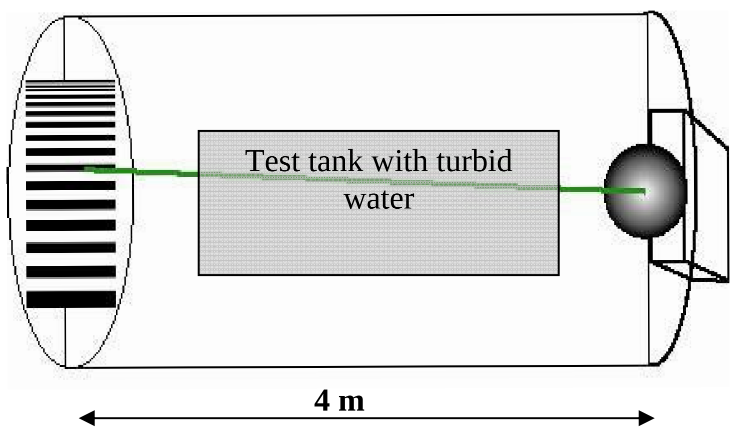

Figure 2: A schematic of the lab experiment performed recently. The figure shows the laser line scan imaging a test target through a turbid media in a test tank.

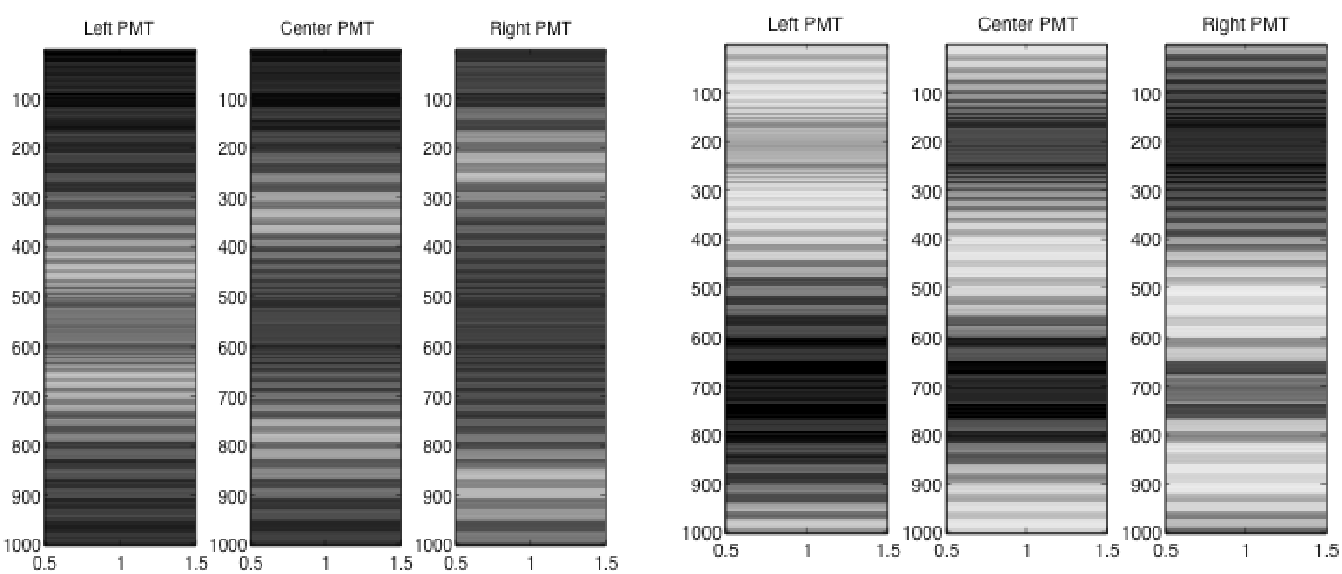

Figure 3: The results of scanning laser beam across the three PMTs in clear water (left) and water with a small amount of Maalox added (right).

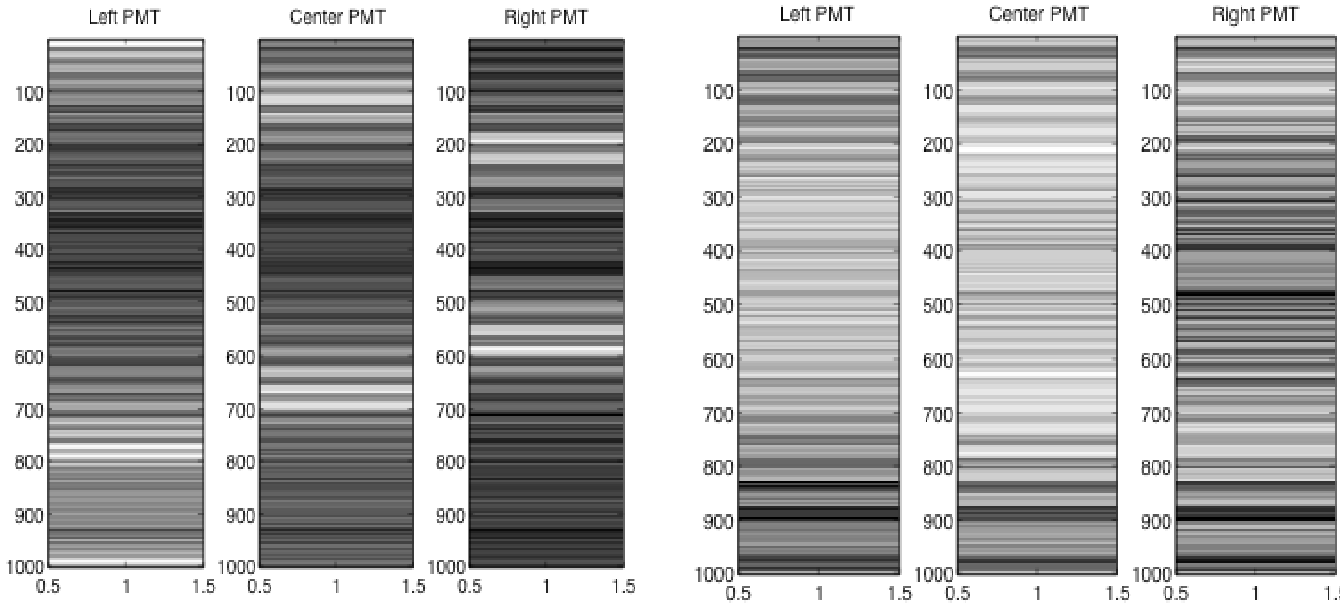

Figure 4: The resultant output of the three PMTs when increasing amounts of Maalox have been added (left to right).

Figure 3 and 4 show images of the test target with the 3 PMTs that are active. As can be seen, as the target is scanned by the laser, each PMT "lights up". The aggregate pattern will ultimately yield an image. As can be seen, the experiments document the decorrelation in the images of the test target as we progress to more turbid water from clear water.

Although these initial tests are promising we are in the process of continuing to work with Aculight to refine the instrument in the context of imaging through turbid water. Computer simulations of the system indicated that excellent extended range images would be available from this device. Further work in our lab and a transition to the deep tank at SIO with turbid water will ultimately reveal the performance envelope of the system and predict its field performance in a range of operational optical conditions.